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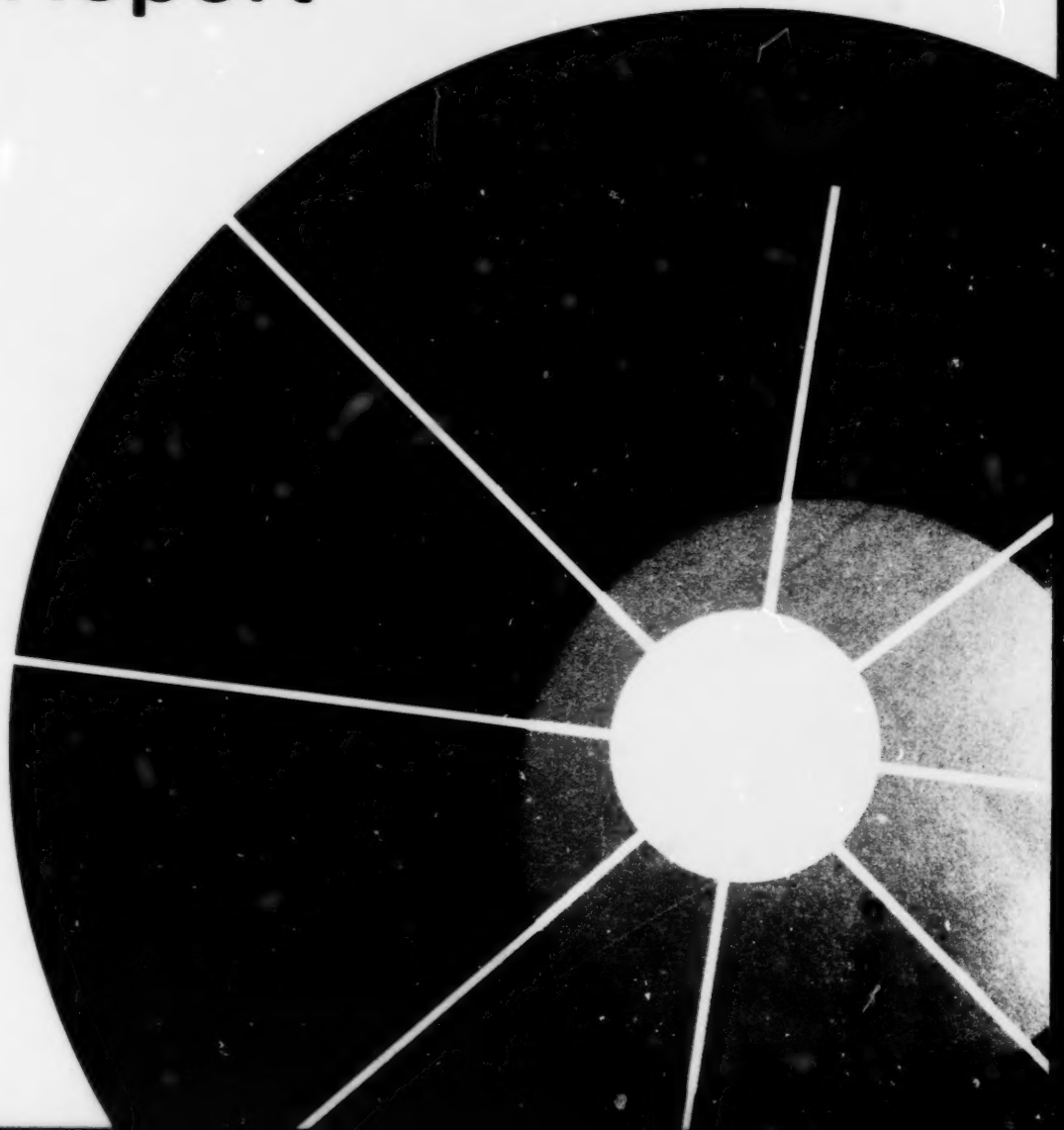
Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report



CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

— To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;

— To create employment in new or existing industries;

— To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

However, neither the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, nor the Government of Canada as represented by Energy, Mines and Resources Canada, accept liability for any errors, omissions, or inaccuracies that may; be included in or derived from this report, nor do they assume any liability with respect to the use of, or actions resulting from the use of, any information contained in this report.

The Weyburn Conservahome

The Retrofit and Rehabilitation of a 1929 Balloon-Framed House with Full Concrete Basement

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

Conducted By

The Saskatchewan Research Council

And Supported By

Saskatchewan Energy and Mines
and
Energy Mines and Resources Canada

Project Leaders: Dave Eyre and Dave Jennings

Miscellaneous
Report FP-20

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This report gives details of the retrofit work conducted on a house in Weyburn, in southern Saskatchewan as part of the Conservahome Project. The Project involved the retrofit and rehabilitation of six houses of various ages and styles, and was funded by CREDA: the federal-provincial Conservation and Renewable Energy Demonstration Agreement. For further details of the project the reader is referred to the Overview Report which makes up part one of this series.

The city of Weyburn lies close to the Saskatchewan-U.S.A. border and was selected during the initial planning stages of the Conservahome Project - one of the objectives being to arrange the six houses to give good geographic coverage.

At the time of house selection, relatively few houses were being offered for sale on the open market, and the choice of a suitable Conservahome was accordingly limited. On inspection of the available houses, it was found that most had concrete basements in very poor condition. This has been tentatively attributed to the prevailing soil conditions; surface sulfate deposits are common in the Weyburn area. The selected house had a relatively good basement, for its age. Also, it was located close to the down-town core and therefore had good demonstration potential.

The Weyburn Conservahome was built in 1929 and contained many of the features common to this vintage. Within the context of the Conservahome Project, this house is of particular interest for the following reasons:

- A balloon-frame construction, which has a relatively low incidence in Saskatchewan.
- The total absence of a vapour barrier, and the impracticability of installing one.
- The problems that are presented by inexpert modifications, conducted over the lifetime of the house.

- The cost escalations that arise when hidden defects are encountered.

- The influence of local codes and by-laws in escalating the cost of rehabilitation work.

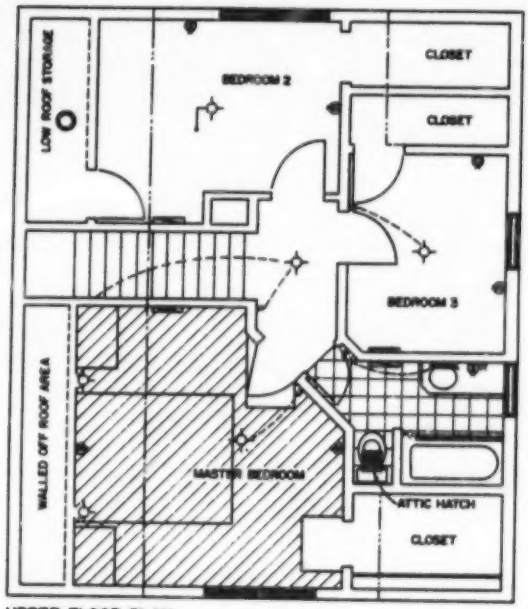
The house is located on the southern half of lot 7, block 34, plan D2537. It is on a north-south street with a west-facing frontage. It was built in 1929 and the original plans were not filed with the city building department.

The plans and west elevation of the house are shown in figure 1 on the two following pages. These are based on detailed measurements conducted as part of the project. The house is a one-and-a-half storey wood-frame structure on a full concrete basement, with a plan area of 63.2 m^2. In its original form, the house was a simple rectangular structure with a 2 by 4 balloon frame and a rafter-type gable roof with half-storey development. It was uninsulated and probably had an interior fibreboard finish.

At some later date, probably around the late thirties. the interior finish was removed, vertical strapping was attached to the walls and a new plaster-on-lath finish was applied to all walls and ceilings. At about the same time, a dormer extension was added on the south side of the upper storey.

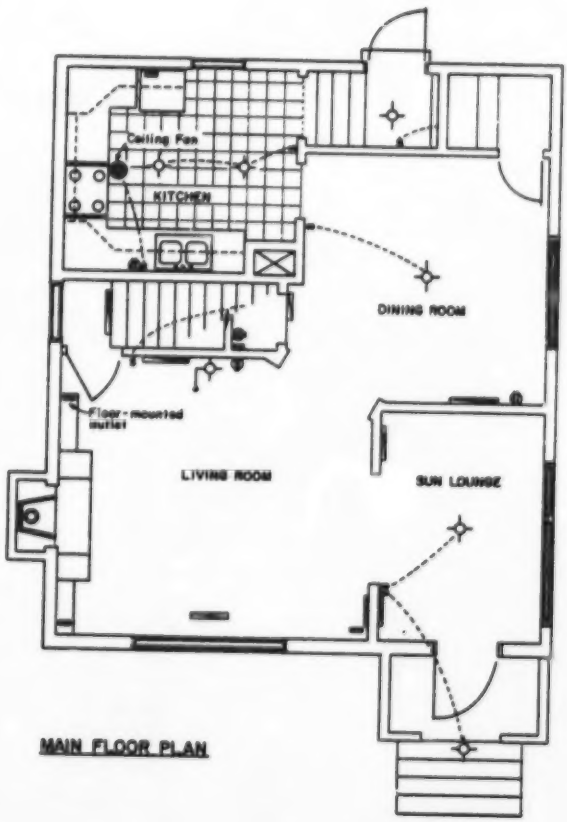
The house shows no signs of further modification until the late 1970's, when major changes were made to the interior finish. The sun room on the main storey and the north-west bedroom were finished in weathered barn board. The kitchen was completely remodelled, and so was the bathroom. A heat circulating type fireplace was installed on the north wall of the living room, and was built into a rectangular chase constructed on the outside of the wall. Changes were made to the electrical and plumbing systems at this time, and some attempt was made to counteract subsidence of the main house frame by installing a new support beam in the basement.

The original windows were predominantly double-hung wood-sash units with matching storm windows. The one in the main bedroom, on the west wall, was replaced by a double-glazed wood casement unit sometime in the 1970's. The house has a fairly large window area on the south wall, but most of this area is shadowed in winter by the neighbouring house on the south. The passive solar gain potential is therefore low.

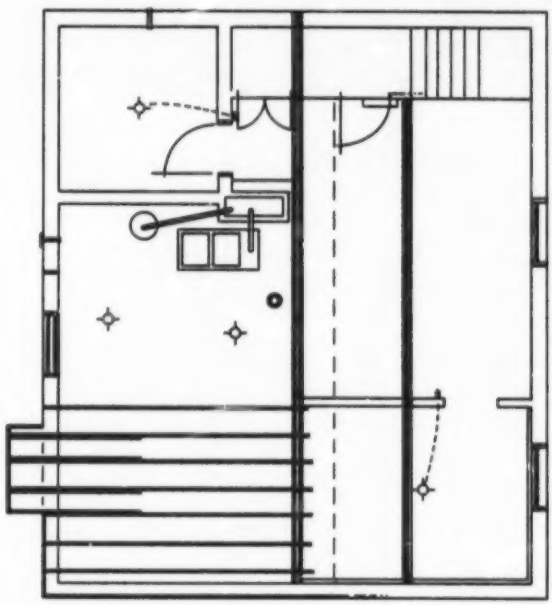


UPPER FLOOR PLAN

Figure 1. Floor Plans and Elevations.

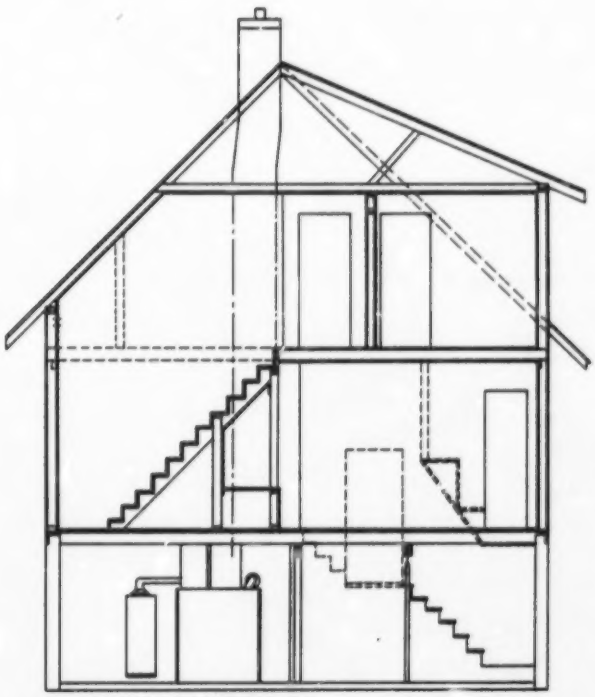


MAIN FLOOR PLAN



BASEMENT PLAN

Figure 1 (contd.)



SECTIONAL VIEW LOOKING EAST

The walls and ceiling were insulated with vermiculite. It is believed that this work was done sometime during the 1960's, though the exact date remains uncertain.

At the time of purchase, the two upper storeys were in better-than-average condition for a 1929 house, with some good rehabilitation work on the interior and a fairly good stucco finish on the exterior. The basement condition was fairly good for a house of this age and in this area. One corner of the basement had been developed as a bedroom, but the quality of this work was very poor. This development was removed at an early stage of the project, to allow a better appraisal of the basement condition.

At the time of purchase, the house had been occupied for at least two years by a family of three, and it is believed that the occupancy patterns were uniform in this period.

The house had three heating systems: a natural gas forced-air furnace, a natural gas domestic hot water heater and a fireplace. From discussions with the occupants, it was ascertained that the fireplace was used intensively during the winter months, and was fuelled by scrap lumber. This large and unregulated heat source made it virtually impossible to estimate the true space heating demands of the house.

With the permission of the home owners, natural gas and electrical fuel bills were obtained from Saskatchewan Power Corporation for the period July 1978 to July 1979. The rate of gas consumption during the summer months was assumed to represent the fuel consumption of the domestic hot water heater. It was further assumed that the same rate of DHW fuel use would apply throughout the year. This allowed a separation of gas usage into its space heat and DHW heat components. The reduced data were as follows:

Space heating (natural gas)	4813 m^3
DHW heating (natural gas)	1104 m^3
Electrical	9604 kWh

During the monitored period, July 1978 to July 1979, the winter season was unusually severe. The space heat consumption was therefore subjected to further analysis, to give the estimated consumption in an 'average' climatic year. This was done by pro-rating the consumption according to the heating degree days, namely by applying the ratio of actual degree days to 30-year-average degree days. This gave the following figure:

Space heating (average year)	4281 m^3

The electrical usage is slightly high for a family of three: about 26 kWh per day as compared with a typical figure of 18 to 20 kWh per day for this level of occupancy.

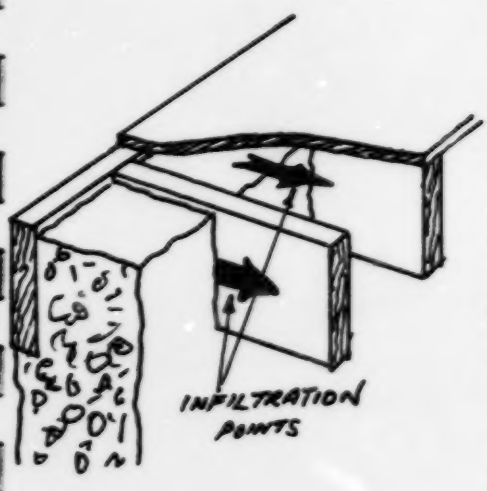
The space heat gas consumption is low for a house of this size and age. Using the measured furnace efficiency of 63.5%, the resulting space heat requirement of the house is 101 GJ (thermal). The space heat requirement of the house can be calculated theoretically by using the estimated heat loss coefficients of the various components of the house envelope. This procedure gives a figure of 153 GJ (thermal). The difference between the two estimates can be explained mainly by the contribution of the fireplace. It can therefore be assumed that the fireplace contributes about 52 GJ (thermal) to the space heating of the house.

If the house had been heated entirely by natural gas, the annual gas consumption for space heating is therefore estimated to be 6473 m^3 - about 51% greater than the average-year figure on the previous page.

4.1 Assessment

The foundation walls had several cracks and a number of areas of alkaline attack. The floor slab was irregular, with extensive alkaline attack in some areas. In a house of recent construction such a basement would be considered very poor, but in a 50-year old basement the condition was very good, and well above average for a house of this vintage. During the original inspection it was felt that none of the basement defects were bad enough to require major rehabilitation work. The basement was equipped with a cold room on the north-east corner, with concrete walls. On the south-west corner, a wood-framed bedroom had been developed, but this obviously had not been used for some time and its condition was very poor. Immediately after purchase this development work was removed to allow a better appraisal of the foundation wall condition. No serious defects were revealed.

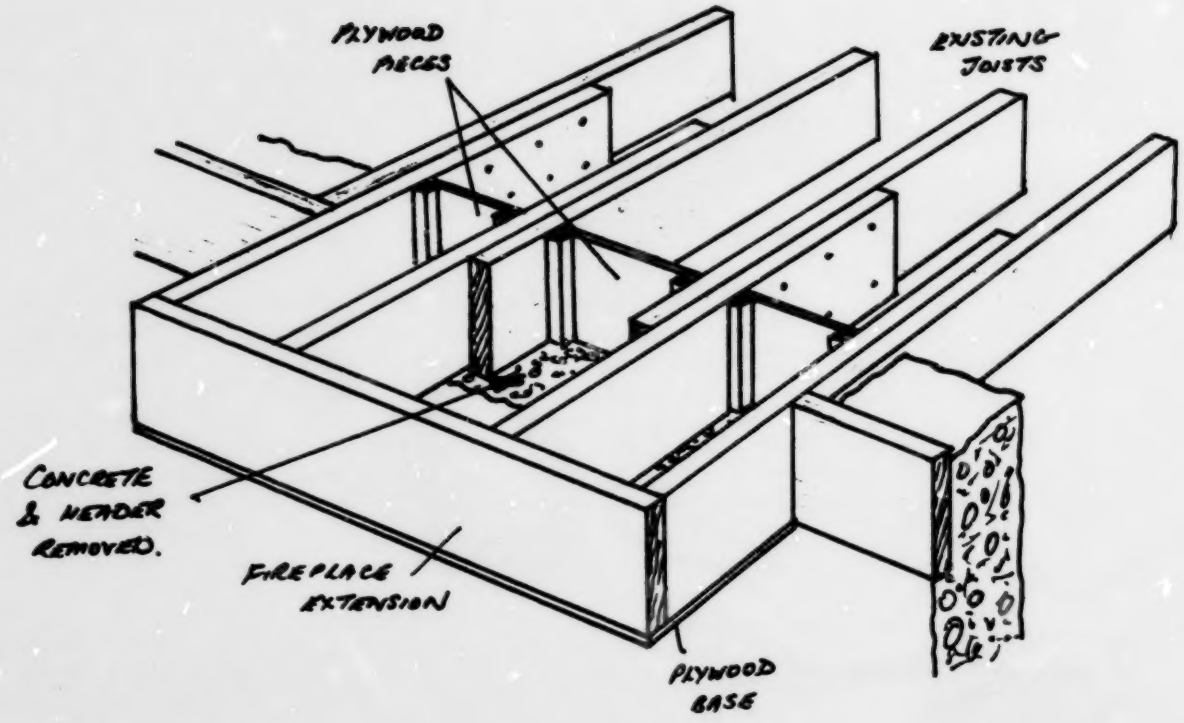
A main support beam with three teleposts spanned the basement ceiling from east to west (see the basement floor plan in figure 1). A new support beam, showing signs of recent installation, had been installed parallel to the main beam and about 1.7 m to the south (see figure 1). This beam was obviously an attempt to arrest or correct the downward slump of partition walls on upper floors. The beam was provided with four teleposts, but the supporting footings did not conform to standard requirements.



The floor joists were set into the concrete foundation wall at the time of pouring - a common practice in Saskatchewan. In normal practice, a space of up to one-third of the joist depth is left between the top of the foundation wall and the sub-floor, but in this case the sub-floor was virtually flush with the top of the foundation wall. The normal processes of wood shrinkage had caused small openings between the joists and surrounding concrete - a source of infiltration.

An unusual feature had been created by the recent installation of the fireplace on the main storey. The fireplace and its chimney were mounted on an extension outside the exterior wall of the house, and were supported on floor joist extensions (see basement floor

plan in figure 1). The concrete had been removed from between the joists in this area. Four pieces of joist were nailed to the existing floor joists and carried through the foundation wall to make a support for the fireplace extension. The holes in the concrete were closed off, inside the basement, with plywood pieces fitted between the joists. These pieces were neither tightly fitted nor sealed, and large infiltration openings were left around this work.



Various electrical cable and plumbing openings were found around the foundation walls, constituting further sources of infiltration. In particular, a substandard cable connection had been installed through the foundation wall to the unattached garage.

4.2 Retrofit Alternatives

With a sub-standard basement, there are basically three retrofit options:

- Do nothing.
- Seal all the accessible infiltration points.
- Seal all infiltration points and insulate the foundation wall.

The first option is justifiable if the basement is in exceptionally poor condition and the house is not expected to last for more than a few years. This was not the case in the Weyburn house; the basement condition could not be described as excessively poor and the house was expected to have at least another twenty years of life.

The second option, sealing only, was the most appropriate for a basement in this condition. The useful life of such a basement can be extended significantly by rehabilitation work, consisting mainly of grouting the various cracks. This, in itself, eliminates some of the main infiltration openings. The infiltration performance of the basement can then be further improved by the caulking and sealing of the concrete-wood joints and other openings. This procedure gives a marginal improvement in the thermal performance of the house, but without insulation retrofit the basement will continue to be a major source of conduction heat loss.

The third option, sealing and insulating, gives the greatest increase in thermal performance, but at the same time is the most costly option. If this option is selected, it is of the utmost importance to put the basement in good condition first, otherwise the insulation and developmental work may be damaged by movement of the foundation and water infiltration through newly opened cracks. This presents a problem: the cause of basement deterioration may not always be obvious; it could be due to sub-standard concrete, water table effects, local soil conditions or various combinations of these. Rehabilitation will correct

the symptoms - for a time - but it may not correct the basic cause of the deterioration. Thus, basement rehabilitation may be nothing but a temporary measure. Even if it is properly done, the causes of deterioration may persist and may destroy the rehabilitation work eventually. Good rehabilitation should therefore be directed not only at the obvious points of deterioration, but also at the conditions that caused these in the first place. Sometimes this may not be possible. Also, in some instances, the state of the art has not advanced to the point where causes can be clearly identified. In general, therefore, major basement rehabilitation and retrofit involves a certain amount of risk. Good practices will moderate the risk, but will not necessarily eliminate it.

If it is decided to seal and insulate the basement, the next step is to decide whether to insulate from the inside or the outside. The outside approach is preferable on technical grounds, since the new insulation protects the concrete foundation walls from climatic temperature swings. On an existing house this approach is often impracticable, since it requires full access to the exterior of the foundation wall. This usually involves costly excavation and backfill work, and will also involve the removal of concrete paths, steps and other permanent structures. The interior approach is usually more practicable since the access is better and the work improves the interior finish of the basement. In some cases this may add to the value of the house at the time of sale. With this approach, however, the concrete foundation is insulated from the warming effect of the house, and will suffer greater temperature swings than previously. This may promote accelerated deterioration of the basement, depending on soil and water table conditions.

4.3 Factors affecting the choice

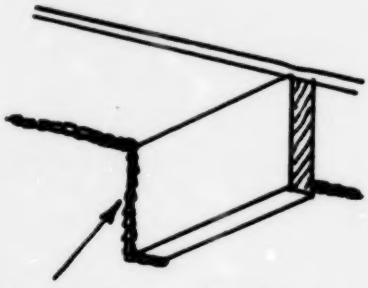
On first inspection, the basement appeared to be in good enough condition to justify retrofit without major rehabilitation. The foundation wall cracks were not extensive and the areas of alkaline attack were small. With the removal of the small amount of devel-

opment work there was good access to all parts of the foundation wall. Grouting and sealing were obvious choices, but there were doubts about the advisability of insulating.

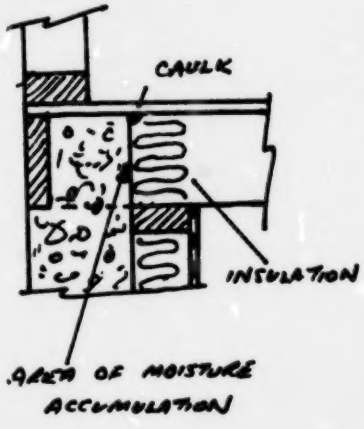
The condition of the basement floor was an important factor. It was in very poor condition and had prevented the development of the basement as useful living space. At first, it was planned to do nothing to the floor. If this approach had been followed, then it would have been preferable to limit the basement work to grouting and sealing - it was felt that this would have been the choice of most homeowners. However, various other factors made it necessary to rehabilitate the basement floor. The plumbing system was found to be in poor condition and it was suspected that the under-floor cast iron sanitary drainage system might need replacing. Also, it was thought advisable to have concrete footings cast to support the teleposts for the new support beam. This support beam, installed a few years previously, needed further strengthening. Consequently, it was decided to install a new basement floor. This would improve the basement space and make it suitable for further development. Therefore, following on this decision, it was also decided to conduct an interior insulation retrofit on the basement walls. This had two advantages: first, it would increase the demonstrational impact of the house; secondly, it would increase the energy efficiency and the market value of the house. It is believed that most homeowners, faced with this option, would decide not to proceed with insulation under these conditions - particularly when considering the remaining useful life of the house. The demonstrational component was therefore an important factor in this decision.

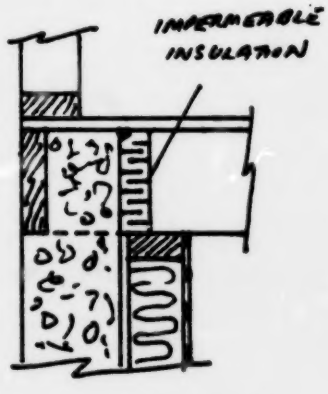
The cold room was an interesting feature of the basement, and is not uncommon in prairie basements. It was therefore decided to demonstrate correct insulation techniques for a cold room. This was made possible by the decision to insulate the basement, and was a contributory factor in the decision.

Having decided to insulate, a further decision had to be made about the most suitable vapour barrier design. Should it be a conventional vapour barrier or a high quality air-vapour barrier? Since the remainder of



CONSTRUCTION ALLOWS GOOD SEALING AT WOOD-CONCRETE JOINT





A BETTER TECHNIQUE

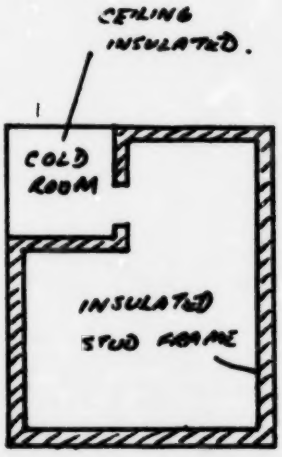
the house had no vapour barrier and it would be difficult to achieve high levels of airtightness, it was thought inadvisable to attempt high levels of airtightness in the basement alone. It was therefore decided to install only a moderately tight vapour barrier. Particular problems were created at the joist header: should this area be insulated, or vapour barriered, or neither? The decision was determined by the details of the construction at this point. The joists were set almost completely into the concrete, and virtually none of the header was exposed inside the basement. Thus, by caulking the wood-concrete joints, moisture would be prevented from penetrating through to the header - where it might ultimately cause rot. It was also decided to install a small amount of insulation between the joists, against the concrete. Since this would have no vapour barrier, some condensation and frost build-up was expected to occur against the concrete. On consideration, it was felt that this would not lead to any structural damage and would be dissipated at the end of the heating season. Ideally, it would have been better to carry the vapour barrier up between the joists, covering the insulation at this point and preventing moisture effects. But it was felt that this would be an expensive solution to a not-too-critical problem. In retrospect, it would have been better to install an impermeable insulation, such as extruded polystyrene, as a tight fit between the joists. This would have been costly - involving precision fitting and fire-resistant protective covering, though it could be done inexpensively by the homeowner.

4.4 Details of the upgrading work*

All development work in the basement was removed. The furnace and water heater were removed and disposed of (the replacement of these items will be discussed later). The basement stairs were removed and stored.

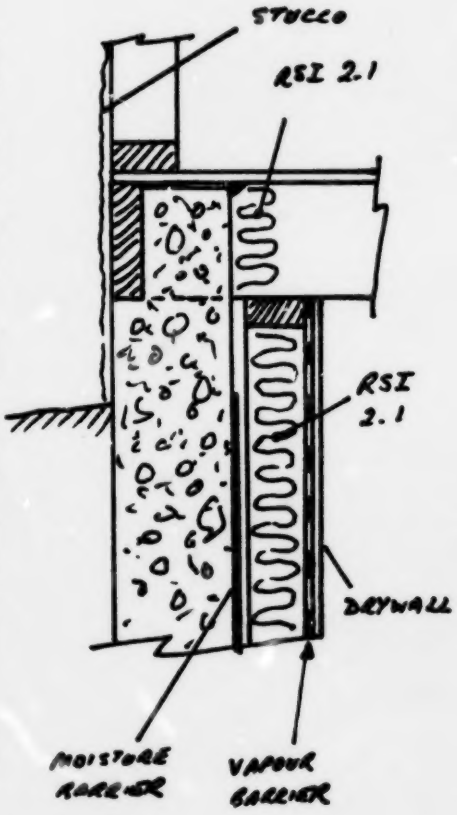
The existing concrete floor and underlying earth were removed. A gravel drainage pad and weeping tile system were installed and the sanitary drainage system was repaired. A new concrete floor was then poured, including new concrete footings for the teleposts.

* The detailed specifications of all upgrading work are given in Appendix I, which consists of specifications taken from the contract documents.



All major cracks in the basement wall were identified and opened up to a depth of 25 mm and a width of 12 mm. The openings were then cleaned and filled with a good quality concrete grout. Large holes, such as those left by obsolete utilities, were filled with mortar. During this work, a section of the basement wall on the north side of the house was found to be in worse condition than originally supposed. A housing inspector was called in, and recommended the complete replacement of a section of this wall. This was done.

All efflorescence was removed from the basement walls with a wire brush, and the walls were then coated with a bitumen moisture barrier from floor level up to grade level. The wood-concrete joints at the top of the foundation wall were caulked, with special attention to the infiltration points around the new fireplace extension. A 38 mm x 89 mm wood frame, with 610 mm centres, was installed to full height around the basement walls. This frame was carried around the warm side of the cold room; the exterior walls of the cold room were not framed or insulated.



Frame extensions were installed around the basement windows and the cold-room door.

The new stud frame was insulated with RSI 2.1 friction-fit glass fibre batt, and then provided with a good quality vapour barrier, with attention to sealing around windows and electrical outlets (newly installed in the stud wall). The vapour barrier was terminated at the top of the stud frame. Small sections of RSI 2.1 batt were installed between the joists at the top of the frame. Finally, the stud frame was finished with 12 mm plasterboard and the stairs were re-installed.

The two support beams were strengthened by the addition of new laminations, and the teleposts were re-installed on the new concrete footings.

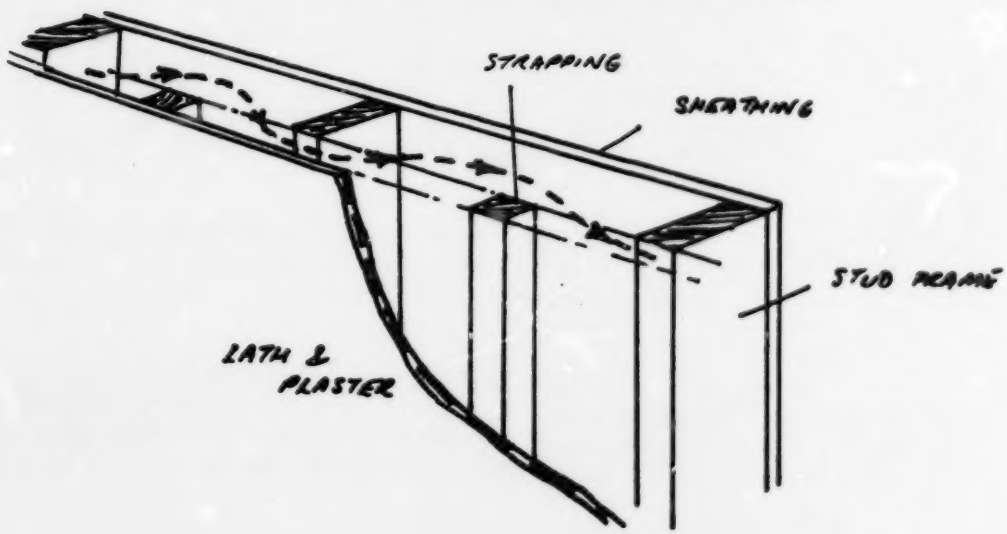
The cold-room ceiling was insulated with glass fibre batt between the joists, and was finished off with plasterboard. A new hollow core door was installed in the cold room and was provided with sealing strip.

5.1 Assessment

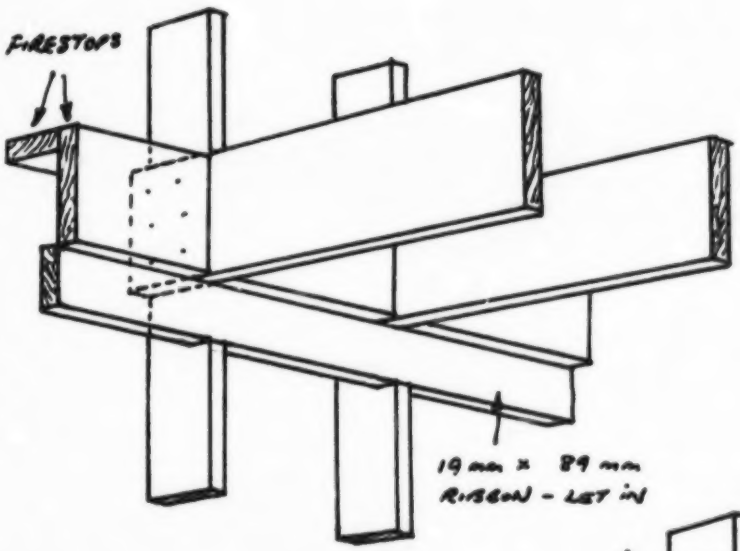
The exterior walls were in good condition, both inside and out. The exterior surface was finished in stucco, which showed some signs of slight disrepair but needed no rehabilitation apart from a new coat of paint. The interior of the house had been re-modelled and decorated recently. The kitchen, sun room, living room and main bedroom had been extensively remodelled, and many of the wall surfaces were newly finished in tile or weathered barn board, with new fitted cabinets and built-in bookshelves.

The tops of the gable walls were visible in the attic, and it was immediately obvious that the walls contained some curious structural features. Some small sections of the wall surface were removed to allow a more detailed inspection. It was found that the walls contained two layers of framing. The main frame was a 38 mm x 89 mm conventional stud frame, on 610 mm centres. The thickness of this frame had been increased by a series of vertical 38 mm x 38 mm strapping on irregular spacings. No explanation for this has been found. Horizontal laths were attached to the strapping and covered with plaster.

Because of the irregular spacing of the strapping, there was a continuous passage around the wall, connecting one stud space to the next:

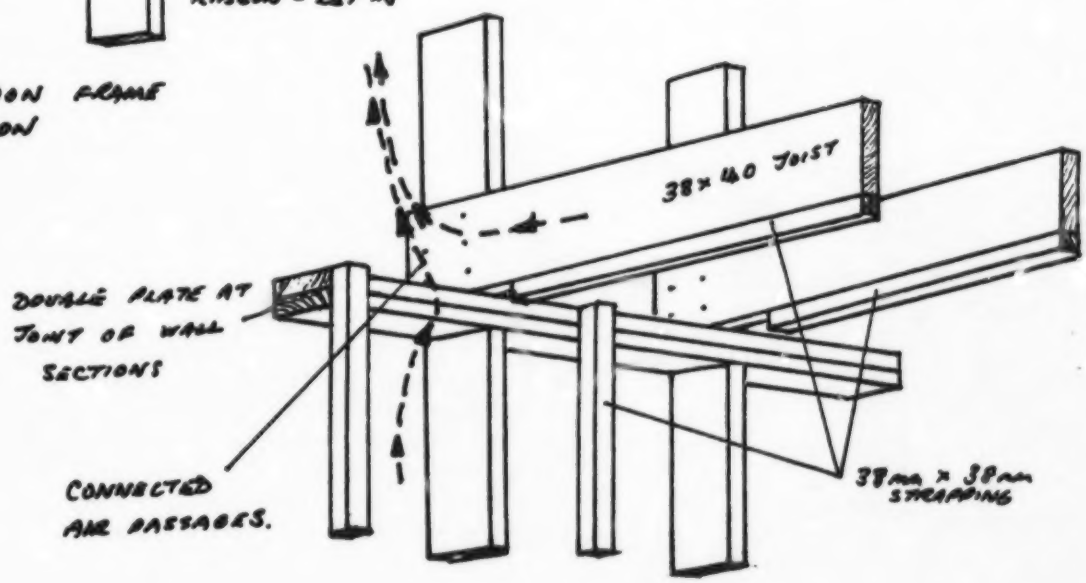


Further irregularities were found in the wood frame structure at the junction of the upper storey floor and the exterior wall. The design can be loosely described as balloon frame construction, though lacking the firestop components. The strapping, mentioned earlier, added to the complications of the design at this point. The two following sketches show an ideal balloon frame construction and the actual construction of the Weyburn house:



TYPICAL BALLOON FRAME CONSTRUCTION

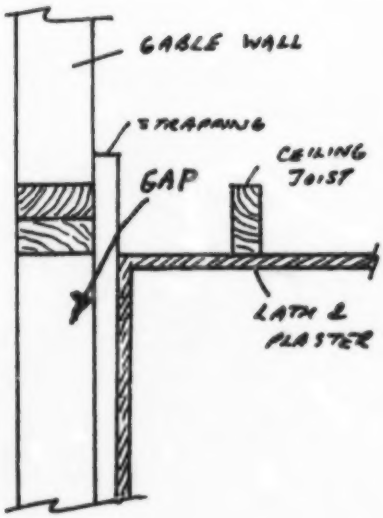
CONSTRUCTION OF WEYBURN HOUSE



The original wall frame appears to have been built as two separate sections, one above the other, each with its own top plate and bottom plate. This gave a double plate at the wall joint. In platform frame construction the floor joists would have been interposed between the two wall sections, but in the Weyburn house the joists were side-nailed to the studs in the upper section, somewhat like a balloon frame. Originally, therefore, the double plate would have served as a firestop. However, with the addition of vertical furring strips an air passage was set up around the edges of the double plate, thereby eliminating the firestop effect.

Since there was no firestop blocking between joists, there was an extensive air passage between each pair of joists, connected to the air passage between the matching pairs of studs. In effect, this constituted a very large air leakage path.

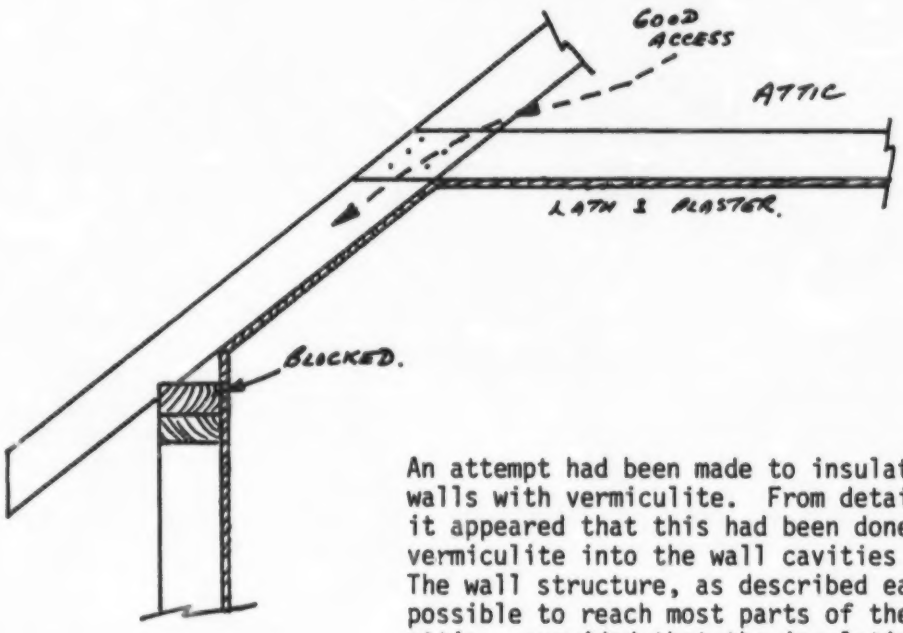
Strapping had also been nailed to the bottom edge of each joist. Here again, the purpose of this modification was not clear.



In total, therefore, the walls had been built and modified in such a way as to give a completely coupled air passage throughout the house envelope, both vertically and horizontally. What is more, this air passage was strongly coupled to the space between floor joists. This had important consequences for both airtightness sealing and remedial insulation work.

One other aspect of the wall design played an important part in the subsequent retrofit design: this was the design detail at the top of the exterior walls - in the attic. On all the vertical wall sections in the attic, namely on the gables and on parts of the dormer extension, the strapping had been carried through into the attic, past the edges of the wall top plates. This created a gap at the top of the wall, and it was possible to look down into the wall cavities at most points.

The main blockages in the wall cavities occurred on the north wall, at the junction between the vertical wall section and the sloping section of ceiling. There was good access to the cavities in the sloping section - from the attic. However, the bottom of the sloping section was blocked by the double top plate of the vertical wall:



An attempt had been made to insulate all the exterior walls with vermiculite. From detailed inspections it appeared that this had been done by pouring the vermiculite into the wall cavities from the attic. The wall structure, as described earlier, made it possible to reach most parts of the wall from the attic - provided that the insulation was loose and flowed fairly easily. Vermiculite was well suited to this method of insulation.

The top sections of wall, near the attic level, had very little insulation. This was probably due to settling of the insulation in the wall cavities. Sections of plaster were removed beneath some windows, to determine how well the insulation had flowed into these areas. The coverage was very poor.

Two large losses of wall insulation had occurred as a result of the recent re-modelling of the house. The first was in the sun room on the south-west corner of the main storey. In re-modelling this room, the owner had removed the ceiling plaster and part of the plaster at the top of the exterior walls. A dropped ceiling, made out of weathered barn board, was then installed. Unfortunately, the

removal of the ceiling and wall plaster allowed the vermiculite to flow out of the wall, creating large empty cavities in the wall above. The vermiculite was still moving slowly down into the joist cavities at the time of inspection. Some of it was falling through the gaps in the barn board the investigation of this led to the discovery of the modified balloon frame structure.

A similar depletion of insulation had occurred around the newly installed fireplace. When the owner broke through the exterior wall to install the fireplace, this must have created a general downward flow of the vermiculite. The lost vermiculite had not been replaced.

At a later stage of the assessment, a detailed thermographic scan was conducted on all the exterior walls. This confirmed many of the features noted above, and revealed several wall areas where occasional blocking had prevented proper insulation coverage. Large uninsulated areas were detected above the fireplace. The thermographic technique was found to be particularly useful in this house. It identified many of the problem areas that would have to be dealt with later.

The wall frame appeared to be in good condition, with no visible signs of moisture damage or rot. In view of the obvious potential for moisture movement into the wall, it was therefore concluded that the walls had in-built mechanisms for controlling moisture build-up. The major controlling mechanism was believed to be the drying effect of infiltrating air, induced by the action of the furnace flue and the fireplace chimney. Since the house was stuccoed, the potential for inward air movement through the house envelope was believed to be small. The main airflow path for infiltration was therefore believed to be from the attic, down the wall cavities and into the house through the air passages along the joists, described earlier. Vermiculite has the ability to absorb moisture, and it was believed that this may have prevented moisture damage to a certain extent.

5.2 Retrofit Alternatives

The required retrofit work fell into two categories: sealing and insulating.

With sealing, the alternatives reduce to a choice of the most appropriate level of sealing. At one extreme it is possible to conduct a simple, inexpensive sealing job; at the other extreme one can attempt a very high level of airtightness, though with a corresponding increase in the cost of the work.

A large number of insulation options exist in this situation, but the choice can be narrowed down by a consideration of the walls themselves. Both the interior and exterior wall surfaces were in good condition, and required no major rehabilitation. Furthermore, the walls had already been thickened by the addition of strapping, and the wall cavity was thick enough (about 130 mm) to accept reasonable levels of insulation. These factors suggested that it would be better to use the existing cavity effectively, rather than add more insulation to the interior or exterior surfaces.

Once this general approach had been adopted, the insulation alternatives then reduced to two basic categories: the type of insulation and the method of installation. The insulation must obviously be of the type that can be inserted into the cavity with minimum damage to existing wall surfaces. The options therefore include loose-fill materials, such as cellulose fibre, mineral wool, glass fibre, vermiculite etc. - as well as foamed-in-place materials such as urethane foam (Note that urea formaldehyde foam had known problems at this time, and was not considered as an option). The choice of insulation usually determines the method of installation, and may include injection, blowing or pouring.

5.3 Factors influencing the choice

The retrofit approach must be designed very carefully in a house of this type, since there is a risk of setting up moisture damage. The house had no vapour barrier, in the accepted sense of the term. The interior wall finish consisted of plaster on lath throughout most of the house. This offers little resistance to the diffusion of water vapour from the house interior into the wall cavity. Some paints offer good resistance to water vapour movement, though it is difficult to assess the magnitude of this effect in a practical situation. Bearing in mind the age of the house, it was felt that the walls might contain enough coats of paint to significantly retard the movement of water vapour.

In most houses of this age, the leakiness of the structure accounts for most of the water vapour movement into the walls. In this instance, the problems of air leakage and water vapour movement were aggravated by the modified balloon frame structure, detailed earlier. This provided strong air leakage paths between the exterior wall cavities and all parts of the interior house structure. Thus, air could leak through an electrical outlet on a partition wall, then up this wall and into the joist cavity, then along the joist cavity and into the exterior wall. From this it will be clear that a very extensive system of air leakage paths existed in this house.

Within practical cost limitations it is virtually impossible to close off these leakage paths - or even to achieve a tolerable reduction in the leakage area. The critical factor is the strong air coupling between the wall cavity and the joist cavity. It is difficult to seal this effectively and cheaply. In a recently developed technique, holes are cut through the floor or ceiling, close to the problem area. Then urethane foam is injected into each joist cavity to seal the area where the joist connects to the exterior wall. This was considered, but was dismissed as being far too costly and impracticable. An important factor was the vermiculite wall insulation, which had flowed from the wall cavity into the joist cavities. It would have been difficult to remove this before sealing.

Even when this sealing technique is applied, the effectiveness of the seal may be impaired by the presence of floorboards, as in this case. The floorboards have air channels running along their joints, and even more work is required to seal these. A new technique involves the drilling of holes through each floorboard joint, then filling the holes with caulk or sealant.

The foam sealing technique is perhaps the best and most obvious way of achieving high levels of airtightness in this type of structure. Its costs were unknown, but were expected to be too high to be justified in this case.

The alternative was to try to seal the air leakage channels at some other part of the structure. The air that leaks through the joist cavities into the wall cavities passes first through the various small openings distributed around the house interior. It was therefore decided to try to seal these points rather than the joist cavities. This meant that all leakage points had to be sealed on all walls in the house interior, including electrical outlets, ceiling fixtures, plaster cracks, gaps at the bottom of walls, etc. Within practical limits, this can never be entirely effective, since several of the air leakage points are inaccessible. These include floorboard joints, hidden cable runs, heating duct runs in walls, and so on.

Accordingly, though it was decided to adopt this technique, it was recognized that it would give only a moderate improvement in the airtightness of the house. Airtightness tests, before and after retrofit, showed a 42% reduction in air leakage rates.

In selecting the most appropriate insulation method, it was thought wise to proceed on the assumption that there would continue to be a high rate of water vapour movement into the exterior wall cavities. Part of this movement would be due to air exfiltration, which, though reduced, might still be high enough to

present a problem. Also, since the wall finishes were generally in good condition, it would have been impracticable to try to introduce a more effective vapour barrier. Therefore, the diffusion of water vapour through the plaster would remain unabated, though the magnitude of this effect could not be estimated with any certainty.

The various insulation options were considered, and were assessed as follows:

Urethane foam:
This would give a relatively high level of insulation and would also produce a considerable improvement in the airtightness of the house. At that time, however, there were concerns about the stability of this insulation material - and the risk of wall discolouration. Also, it was felt that it might be difficult to restrict the area of application of the foam; it was expected that a large amount of the foam would find its way along the joist cavities.

Cellulose fibre:
This could be blown into the wall cavities, but it was anticipated that there might be some difficulty in reaching awkward parts of the walls. In the event of moisture build-up in the walls, this insulation could be expected to deteriorate more rapidly than other options.

Blown glass fibre:
Again, some difficulty was anticipated in reaching awkward wall sections. This insulation would not be much impaired by moisture build-up. However, if excessive build-up occurred, this would accumulate as water pools at the bottom of the wall cavities in spring, and might lead to extensive sill plate damage. At the time of this project, the blown glass fibre industry was still in its infancy in Saskatchewan. There were some concerns about quality control, and some difficulties in finding installers with the right equipment for the job.

Vermiculite:
Compared with other loose fill insulations, this had a relatively low thermal resistance per unit thickness and a relatively high cost per unit of thermal resistance. Its main advantage lay in the fact that it

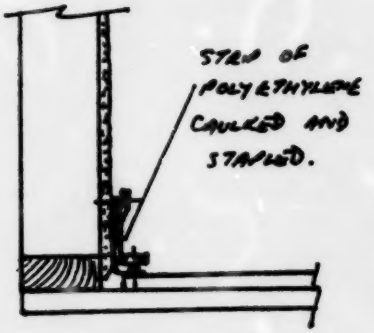
absorbs moisture readily (it is used as a moisture-retaining mulch in horticulture). Thus, if there were any moisture accumulation in the wall cavities, this would be absorbed in the vermiculite and there would be less tendency for water to build up on the wall sill plate in spring.

It was decided to use vermiculite, partly because most of the wall cavities were already insulated with it, and partly because of its potential advantages in moisture control. Once the moisture is absorbed in the vermiculite, it will be given off slowly by evapouration during the summer months, and will be dissipated from the wall structure with reduced risk of causing moisture damage. This, at least, was the working hypothesis. There has been no opportunity to research the long-term behaviour of vermiculite under these conditions.

It was proposed to install the vermiculite by pouring, using the available openings in the attic. These would give access to most parts of the walls, but it was appreciated that it would be necessary to core the walls at some points, to give access to partly blocked areas. Experiences with the vermiculite during inspection indicated that it would flow very easily in the wall structure.

5.4 Details of the upgrading work

Sealing:



All baseboards were removed, to permit sealing at the base of walls. In many instances this caused damage to the plaster, which then had to be repaired. Sealing was applied to the gap at the base of the walls. On the first attempt, aerosol cans of urethane foam were used. It was found difficult to control the size of the foam 'bead', which was usually too large. When it dried, it had to be trimmed before the baseboards could be re-installed. This was time consuming. Eventually, all the urethane sealant was removed and the gaps were sealed with strips of polyethylene, caulked and stapled to the wall and floor.

Both of the sealing techniques were found to be time consuming, and were probably too costly to be applied routinely. In most cases, where the air gap is small, it should be possible to apply a thin bead of sealant without removing the baseboards. But where the gap is large, as in this case, some other technique must be developed. The technique will have to be adapted to actual conditions. For example, different techniques might be necessary for fitted carpet areas and wood floor areas. It is not always essential to remove the baseboard, provided that all air gaps are sealed around it. This may require a bead of sealant along the top of the baseboard, in which case the sealant type has to be carefully chosen - a paintable type is usually desirable.

The face plates were removed on electrical outlets in the walls. A bead of caulk was applied to their back face, and they were re-installed.

Fireplace:

An access hole was cut in the fireplace chimney chase on the outside of the house. Plywood was installed over the area through which the vermiculite was escaping.

Sun Room:

This was the only place in the house with easy access to the ends of the floor joists on the upper storey. A large amount of vermiculite had escaped from this area as a consequence of re-modelling changes. Sections of plywood were installed between the joists, to hold back the wall vermiculite. Then the area was sealed with sections of polyethylene, caulked and stapled around the edges. The sketch on page 17 gives some idea of the complexity of working in this area. The work was time consuming, but was a necessary preparation for the subsequent insulation work.

Insulation:

All inspection holes were repaired, and any other major openings and cracks were sealed. Vermiculite insulation was then poured into the wall cavities, using the openings in the attic. Some difficulties were experienced in some sections of the wall, and it was necessary to agitate the vermiculite with long rods to make sure that no cavities were left.

Special attention was given to the sections of wall beneath windows. Holes were cored through the window sills at the point where the window sash meet the sill. The location of the core holes was chosen to effectively hide from view all repairs to the sill after insulating was completed. Insulation was installed and the holes were repaired by plugging the holes with 25 mm fir dowelling material. The window sill was then sanded and repainted.

6.1 Assessment

The roof was a rafter type construction with a pitch of about 1-in-1. There were few braces and good access throughout the attic. The framing and sheathing was sound, with no significant sag in the rafters. The shingles were old, but did not appear to be leaking.

The ceiling consisted of lath and plaster on 38 mm x 89 mm joists, spaced on 410 mm centres. The insulation consisted of about 75 mm of mixed wood shavings and vermiculite.

A brick chimney, a vent stack and a kitchen fan duct passed vertically through the attic. These had been sealed fairly well with oakum and rag where they passed through the ceiling, and the existing work appeared to be adequate. There were signs of water discolouration on both the chimney and the kitchen fan duct, indicating that the flashing would need some attention. The brickwork on the chimney, inside the attic, was in good condition.

The attic was accessed through a very small hatch located above the lavatory in the upper storey bathroom. Access was difficult. The hatch was poorly sealed, and constituted a major source of air leakage in a relatively humid part of the house.

The main source of air leakage was found at the top of some partition walls. The strapping modifications referred to earlier, had also been applied to some partition walls. In some instances the strapping had been carried past the top plates of the partition walls, into the attic space. This created major air gaps at the top of the walls, with the details being similar to those in the sketch on page 18.

The electrical work in the attic showed a variety of 'generations' of upgrading. Some of the original knob-and-tube wiring was still in use. Other installations consisted of standard electrical

cable, dating back to the 1950's. There was a small number of standard ceiling light fixtures protruding through the ceiling. Also, over the re-modelled bedroom, a recessed pot light showed signs of recent installation. Some cable holes were found at the tops of partition walls, but the infiltration through these would have been small compared with the air movement through the large strapping gaps.

The attic ventilation consisted of a small vent on each gable. It was felt that these contributed little to the total air movement through the attic. Most of this air movement probably came through the rafter eaves and the various sheathing gaps.

6.2 Retrofit Alternatives

The attic suffered from two major defects: the combined area of all air leakage points was very large and the insulation level was very low. Each of these factors called for considerable improvement.

In such instances, the highest priority should be given to sealing the air leakage openings. This reduces heat loss through air exfiltration, but its main purpose is to reduce the large movement of humid house air into the attic - where it can condense and lead to moisture damage. The lath and plaster construction does not lend itself easily to standard sealing techniques, therefore special techniques must be applied.

Most types of batt or loose-fill insulation could be employed in this attic, but the final choice should be determined by the anticipated moisture conditions after retrofit. If the risk of moisture exfiltration is large, then the selected insulation should be reasonably immune to moisture effects. Examples are glass fibre batt, loose-fill glass fibre, mineral wool batt or loose-fill, and vermiculite. If the risk of moisture damage is small, cellulose fibre would also be a viable option.

In addition to sealing and insulating, some thought must also be given to remedial vapour barrier work, as a way of reducing moisture diffusion into the attic through the lath and plaster. The need for this work is determined mainly by the effectiveness of the ceiling paint as a vapour barrier.

6.3 Factors affecting the choice

The house is a one-and-a-half storey unit and probably has a pronounced stack effect at the ceiling level. This will promote exfiltration of humid house air into the attic. This process is supplemented by exfiltration into the house walls. The walls are covered externally with stucco, which inhibits the movement of air and moisture through the wall envelope. For air and moisture moving through the walls, the easiest path is up the wall cavity and into the attic, via the large openings at the tops of the exterior walls. Similar comments apply to the partition walls. As a result, the movement of air and moisture into the attic can be assumed to be large. In view of this, it is surprising that the attic showed very little sign of moisture damage. The explanation can probably be found in the ventilation air flow through the attic. The gable vents were small, but the air flow through the eaves was believed to be large.

Therefore, although the attic had many defects, it appeared to operate satisfactorily from a structural point of view.

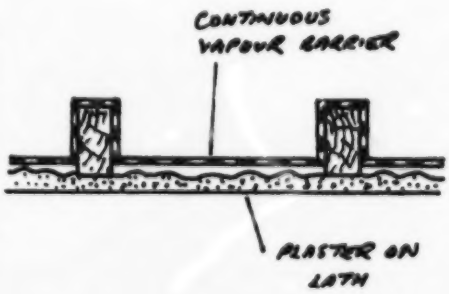
When insulation is added to an attic in this condition, the attic will operate at a colder temperature. Therefore, there is a risk that the exfiltrating moisture will condense or form frost in the attic. A simple insulation retrofit may therefore create moisture problems where none existed previously. Therefore, as a pre-requisite to insulation, it is essential to reduce exfiltration effects to a practicable minimum.

The main air leakage points, in order of importance, were as follows:

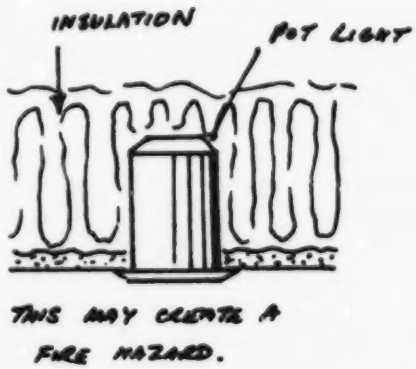
- Openings between the vertical strapping at the top of some partition walls;
- Openings around electrical fixtures in the ceiling;
- The attic hatch;
- Small gaps around vent stacks and chimney.

If the ceiling had been equipped with some kind of vapour barrier material, it would have been possible to close off most of the air leakage points with extra pieces of vapour barrier material. However, the working surface consisted of the reverse side of plaster-on-lath, which was very uneven. Two choices were therefore presented:

- To install a complete vapour barrier across the ceiling.
- To seal only around the air leakage points.



It would have been very difficult to install an effective vapour barrier across the ceiling. This would have involved the careful installation of a continuous sheet of polyethylene, fitting closely to the existing plaster-on-lath and ceiling joists. In view of the age of the house, and the assumed vapour barrier effect of the several coats of ceiling paint, there was felt to be little justification for major remedial work of this type. Instead, it was decided to pursue the second choice and seal around the air leakage points. This meant that special care would have to be taken in achieving a good seal to the existing plaster-on-lath surfaces.



A special problem was presented by the recessed pot light over the main bedroom. With the addition of ceiling insulation this light fixture would overheat and might possible become a fire hazard. The best procedure, in such cases, is to remove the pot light. If it were to be retained, it would be necessary to construct a large heat-dissipating box over the unit.

With a leaky attic hatch there are two options: seal it or re-locate it where it does not present an air leakage problem. In this instance, the hatch was very small and poorly sited for access to the attic. It was decided to re-locate the hatch on the gable wall of the attic, partly to give better access for retrofit work and partly to obtain some idea of the costs of this retrofit option.

Assuming that the ceiling paint provides a good vapour barrier, then, with proper attention to the air leakage points, as defined above, the rate of moisture movement into the attic will be much reduced. Therefore, it was felt that the existing 'ventilation' system in the attic would give adequate control of moisture build-up. It is practically impossible to quantify this kind of decision; the mechanics of attic ventilation are difficult to assess and almost impossible to measure. The assessment must therefore be largely subjective.

Given reduced moisture movement and adequate ventilation, the choice of insulation type is fairly uncritical. Vermiculite was dismissed as being too expensive. The choice was therefore concentrated on the commonly-used batt and loose-fill materials. The authors of this report have always favoured loose-fill in preference to batt, mainly because it can be installed easily around the various irregularities in the attic, without leaving air circulation voids beneath the insulation. The main objection to loose-fill materials is that they tend to settle with time and their effectiveness is reduced. In this instance, it was decided to use a loose-fill material. The two main options - namely those most easily obtained through suppliers at that time - were cellulose fibre and glass fibre. The latter has the greater resistance to moisture damage, and was chosen because of lingering doubts about the possibility of moisture accumulation in the attic.

An insulation level of RSI 8.0 was selected on the basis of cost-effectiveness, though a smaller level would have been more consistent with the general level of energy conservation in the rest of the

house. The existing ceiling structure was judged to be sound enough to support the extra load of insulation.

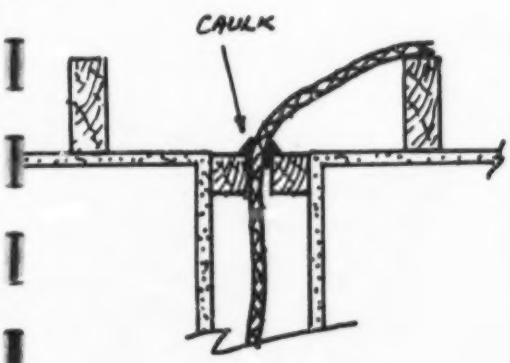
The electrical problems will be discussed in a later section, but it will be useful here to refer to the hazards that can arise when applying extra insulation around electrical wiring in attics. The electrical insulation on cables is usually rated for operation at a certain maximum temperature, and may deteriorate to a hazardous condition if exposed to temperatures above the rated level. The addition of more thermal insulation may raise the cable temperature above the rated level, and this factor should always be taken into consideration when insulating attics. It is always advisable to seek the help of electrical inspectors before proceeding. In this instance, the attic contained a range of electrical cable types of different ages, and some upgrading was necessary.

6.4 Details of the upgrading work

The existing vermiculite insulation was moved to the outside edges of the attic and piled on top of the wall cavities, to act as a 'hopper' supply in the event of insulation settling in the walls.

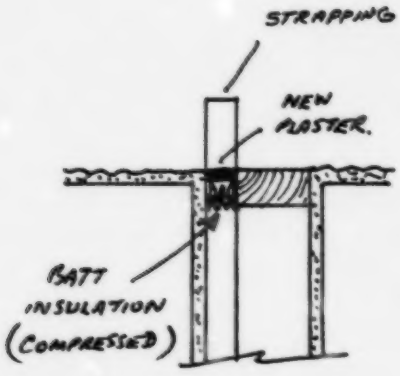
The existing attic hatch was blocked in and sealed. A new attic hatch was installed on the east gable wall, and was provided with a new air vent.

The existing recessed pot light was removed and the hole was repaired with plaster. It was not considered necessary to replace this pot light with any other type of ceiling fixture.

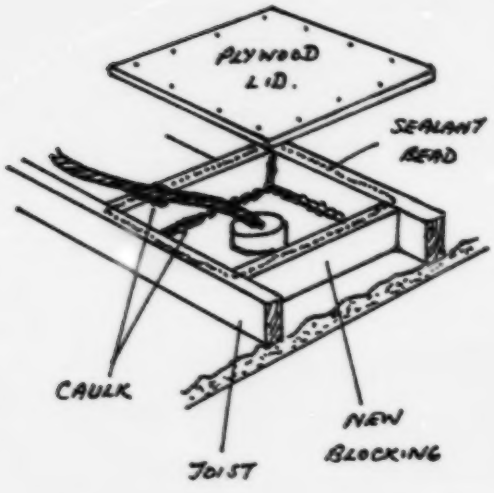


After upgrading some of the electrical circuitry, caulk was applied around the cable holes in the tops of the partition walls.

Gaps around the chimney, vent stack and kitchen fan duct were sealed by installing oakum.



Where large gaps existed at the tops of partition walls, glass fibre batt was stuffed into the gaps to provide a base for remedial work. Plaster was then applied across the top of the gap and was bonded to the existing plaster on each side, making an airtight seal across the gap.



Special attention was paid to the sealing around electrical fixtures. The roughness of the plaster-on-lath made it difficult to seal around the fixtures using polyethylene sheet and sealant. It was therefore decided to construct a sealed box around these problem areas. First, blocking was installed between joists to create a four-sided frame around the fixture. The joints were caulked, and the electrical cables were routed through grooves in the top of the frame, which were then sealed. A bead of sealant was run around the top of the frame, and a plywood lid was nailed in place. This procedure was found to be very effective, and has many advantages over the vapour-barrier techniques that are normally used.

After the ceiling had been thoroughly sealed, loose-fill glass fibre was installed to a depth of about 360 mm.

During this attic work it was noted that the shingles and the flashing around chimney and vents were worse than they appeared during the original inspection. In consultation with building inspectors it was decided to re-shingle the roof and conduct remedial work on the flashing.

No major problems were experienced in the attic retrofit, though the high location of the new attic hatch created some difficulties.

7.1 Assessment

The front door consisted of a main unit and a storm door. Both were wood-framed with large glass inserts. Their condition was poor and the seals were badly deteriorated.

The rear door was exceptionally bad. It consisted of a single door built to storm door specifications rather than those of a proper exterior door. It contained single-glazed glass inserts, and the wood panels were of thin plywood. There were no seals. Large air gaps were noted at the top and bottom; the air gap was about 12 mm wide at some points along the top of the door. At the time of inspection it had been snowing, and a small amount of snow had collected on the floor just inside the door.

The rear door, in particular, was contributing significantly to the heat losses from the house, both by infiltration and thermal transmission.

The windows in the wood-frame storeys were generally in good condition, though requiring some re-painting. The majority of the windows consisted of double-hung wood-framed units, with wood-frame storm units. The main bedroom window had been replaced (probably more than 10 years previously) with a double-glazed wood casement unit, still in good condition. The window in the main living room was a fixed double-glazed unit, in good condition but requiring some re-painting.

The basement windows - three in all - were in poor condition and required some rehabilitation. All were installed originally as double units, with separate outer and inner windows. The window on the north wall of the basement was still in this form, but the two on the south wall had regressed to single units.

Generally, the windows were considered to be sound, with good thermal transmission performance for their age. The infiltration performance was judged to be poor, partly due to the slight deterioration in condition and partly due to the excessive area of openable sections.

7.2 Retrofit Alternatives

With both doors and windows there are generally three options for improving the thermal performance:

- Rehabilitation
- Thermal upgrading, involving some new construction.
- Complete replacement.

In deciding on the best retrofit approach, it must be remembered that windows lose heat both by thermal transmission and by air leakage. The latter may be the dominant factor if the condition of the window has deteriorated to the point where major gaps have appeared.

Rehabilitation is recommended where the window has an acceptable thermal transmission design (double glazing at least) but where the seals on the openable sections have deteriorated. This can happen when the frames warp and cracks open up.

Thermal upgrading may be necessary when it is not possible to bring the windows up to requisite standards by simple rehabilitation procedures. Thus, if a window is in fairly good condition but has only single glazing, some construction work would be advisable to convert it to a double-glazed unit.

Complete replacement is advisable when the window is badly deteriorated - to the point where the structure is not sound enough to justify rehabilitation.

The same range of options applies to doors. For most houses the doors are usually in good enough condition to justify a simple rehabilitation approach - such as the installation of new seals. If the door is in good condition, but has a poor thermal transmission performance, this can be improved by adding a storm door as a thermal upgrading measure. If the door is beyond repair, total replacement becomes necessary.

When replacing an exterior door, one is faced with the choice of solid-core or thermal types - the latter consisting of a sheet metal envelope with a foam insulation interior. Each type is subject to some kind of deformation: the wood-core types warp and the thermal types can deform through differential expansion, due to temperature differences between the interior and the exterior. This means that both types require good seals, flexible enough to accommodate the range of deformation that can be expected. Generally in the retrofitting of doors, too little attention is paid to the sealing aspect. At the time of this project, solid-core wood doors offered a marginal payback advantage over thermal types, but in the last two years the relative costs have changed and there is now little to choose between the two.

There is some difference of opinion about the merit of storm doors. These units can improve the thermal performance of the door design under ideal circumstances, but in practice it is doubtful that they contribute much. In a door unit, it is desirable to seal the main door as effectively as possible. This means that the storm door should be installed with poor seals, so that one door can be closed against the other easily, without air compression effects. If this is done, then air can circulate through the space between the two doors, thereby short-circuiting some of the thermal advantages of the storm door. The main advantage of the storm door lies in the protection it offers to the main door unit. It reduces the infiltration of dust, snow and ice, which might impair the seals on the main unit. It also plays a useful part in providing air circulation in summer, through fly-screen inserts.

Consequently, the decision to use storm doors is usually a subjective one, based on personal preferences. They do not contribute significantly to the overall thermal performance of a house, and have a poor cost-effectiveness when assessed on this basis.

7.3 Factors influencing the choice

The rear door presented no problems in choosing a retrofit approach; it was so bad that the only option was complete replacement. The front door was in moderate condition, and was a borderline case in which the required rehabilitation would not have cost much less than complete replacement. It was therefore decided to replace both doors, partly to give a consistency of design and conditions on both units. Integral solid-core wood units, with fitted storm doors, were selected. The choice of wood units rather than thermal ones was justified on the basis of cost-effectiveness (though see earlier remarks about recent changes in relative costs). The storm doors were chosen partly for summer ventilation action and partly for protection of the main door units.

The double-hung window units were generally in good condition, requiring minor rehabilitation work such as repair of putty and re-painting. However, it was noted that some of these units were provided with an unnecessarily large area of openable section. The dining room and rear bedroom windows consisted of two double-hung units, side by side. The sun room window consisted of three double-hung units. It was felt that one openable unit would provide adequate ventilation in each case. Hence, one unit in each room could be retained for ventilation, and the others fastened and sealed to reduce infiltration.

When sealing a double-hung unit, with an attached storm unit, care must be taken to ensure that the main window is more tightly sealed than the storm, otherwise moisture will exfiltrate from the house into the window cavity, and will find it difficult to escape. This will lead to condensation and frost build-up on the storm window.

When faced with rehabilitation of a double-hung unit, which is to be retained as an openable window, it is difficult to install seals that will eliminate air leakage when the window is closed. If the seals are effective, they make it difficult to raise and lower the window. Conversely, if the seals are loose enough to permit this movement, it is doubtful that

they would serve much purpose in the first place. If the windows are to be sealed in-situ (ie. without removing them from the house), then the range of weatherstripping options is small and there is no outstandingly good technique available to the do-it-yourself craftsman. Some manufacturers make good plastic weatherstripping materials, suitable for double-hung windows, but to install these it is necessary to have millwork done on the sashes, to accept this weatherstripping. This is often impracticable. In this instance it was decided to use simple foam weatherstripping techniques, applied to the window in-situ. Problems were encountered and no good solutions were found.

The kitchen window, a double-hung unit with storm, was in good condition and required minor rehabilitation. However, it was decided to replace this unit with a new locally-made design - as a demonstrational feature. The new unit was triple glazed with extruded vinyl framing, and represented the state of the art in window development, at that time.

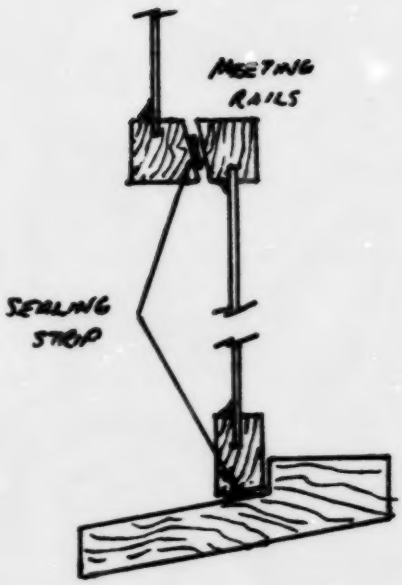
The basement windows required frame extensions, to tie in with the insulated stud frame being installed in the basement. It was decided to design the frame extensions so that the inner windows would be located almost flush with the new plasterboard finish. When upgrading basement windows some consideration has to be given to the aspects of ventilation and safety. A basement window is sometimes regarded as an emergency exit in the event of fire, and may also serve as a means of ventilating the basement in summer. These factors become important when the basement area is divided into rooms, but they are less important when the basement consists of a large, undeveloped area. In some instances the existing building codes or fire codes may affect the retrofit design. No such constraints were identified for the Weyburn house, and it was therefore decided to make the windows fixed sealed units.

7.4 Details of the upgrading work

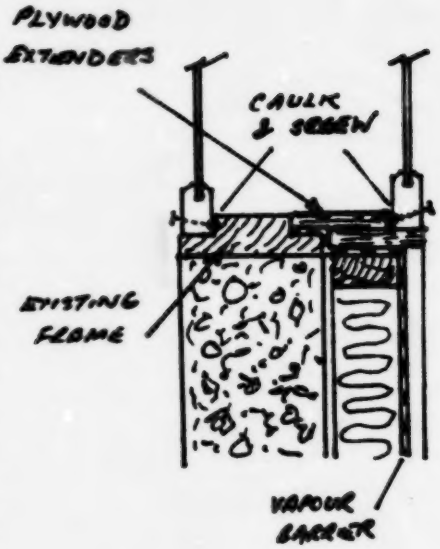
The existing exterior door units were removed and replaced with new combination units, consisting of a solid-core door and a storm door with fitted weatherstripping. The gaps between the jambs and the stud frame were sealed; caulk was used in places where the gap was narrow, and oakum packing was used on wide gaps. Note that the oakum packing should not be overcompressed in this application, since it may distort the door jambs.

All storm windows were removed and rehabilitated. This work consisted of replacement of cracked panes, replacement of damaged putty, sanding and painting.

The double-hung window units were divided into two categories: those that were to be retained as openable units and those that were to be permanently fixed and sealed. One openable unit was left in each room for ventilation purposes. On the fixed, sealed units, caulking was applied around the openable section to seal all air gaps. The openable section was then fixed firmly in place with concealed screws. The units were then sanded and painted, and the storm windows were provided with foam sealing strips and screwed firmly in place.



On the openable sections, the moving window section was removed and all woodwork was sanded and painted -both on the removed section and the main window unit. Foam sealing strips were applied to give as good a seal as possible with the window closed. In practice it is difficult to seal the side edges with foam strip, and the technique is only effective on the meeting rail and the bottom sill. The storm windows on these units were provided with sash adjusters to allow them to be opened easily in summer, and were provided with foam sealing strips before being re-installed. These strips should not give too tight a seal, otherwise moisture will not be able to escape from the space between the two windows, and condensation or frost build-up may occur.



The kitchen window was removed and replaced with a vinyl-framed triple-glazed unit, of local manufacture. A perfect size match could not be obtained with the manufacturer's standard stock, and it was necessary to modify the rough opening in the wall to take the new unit. This sort of problem will often be encountered when replacing windows, and it may involve significant cost penalties. The gaps around the new window frame were sealed at the wall interior with urethane foam, using an aerosol capsule.

The vapour barrier on the basement wall was caulked and stapled to the existing basement window frames. This work was then concealed and protected with frame extensions, which were designed to accept an interior window unit flush with the drywall. The exterior units were rehabilitated: cracked panes were replaced, putty was repaired and the units were sanded and painted. The existing frames were sanded and painted, together with the new frame extensions. The inner and outer window units were then caulked to make an airtight fit, and were screwed in place.

8.1 Assessment

The house was equipped with a natural gas furnace and domestic hot water heater, with flue connections to a brick chimney (see plans in figure 1). These were old units (20 years or more) and were in poor condition, with extensive areas of rusting on the bodywork. The warm air outlets and cold air returns were poorly positioned, and some short-circuiting of flow was occurring in some rooms - namely, the warm air duct was situated close to the cold air return and there was a tendency for the warm air to flow from one directly to the other, without doing much to heat the room. The humidifier was corroded and due for replacement.

The furnace filter was found to be clogged with a layer of dust, several millimetres thick. This was restricting the circulating airflow through the unit, and was thereby reducing its thermal efficiency. It was decided to measure the thermal efficiency with the filter in position, then again with the filter removed. The respective measurements were 63.5% and 68.2%, indicating a 4.7% reduction in efficiency due to the dirty filter.

A thermal efficiency of 68.2% is quite good for a natural gas furnace of this age, and would not justify replacement on the grounds of energy conservation. However, it was quite obvious that the furnace (and the water heater) were near the end of their useful life and needed replacing - mainly as a rehabilitation measure. This would give the opportunity to demonstrate some of the factors involved in replacing such units.

8.2 Retrofit Alternatives

When replacing a furnace as part of a major retrofit, the following factors must be taken into consideration:

- The reduced capacity requirements of the furnace, by virtue of the improved thermal efficiency of the house.

- Possible problems with combustion air supply, if the house is sealed too tightly.

- The potential for inducing moisture problems in the walls, due to the reduced activity of the furnace.

- The best selection from a range of furnaces of different designs with different thermal efficiencies.

Regarding the capacity of the furnace: furnaces are generally oversized for the heating needs of the house. If the house is retrofitted, its heating needs will be reduced and the furnace oversize factor will be increased. The furnace oversize factor is the ratio of actual heating capacity to that required by the house. If the oversize factor is large, the true efficiency of the furnace - known as the 'seasonal efficiency' - may be typically 5% less than with a properly sized furnace. When a furnace is to be replaced as part of a larger retrofit operation, this creates the opportunity to install a furnace with a capacity more suited to the needs of the house.

If the house becomes too tightly sealed, as a result of other retrofit work, the air leakage through the house envelope may be too small to meet the combustion air requirements of the furnace. As a result, the furnace will have to compete with other combustion units, such as fireplaces. It may also have to compete with air management systems such as kitchen fans, etc. When this happens, there is a risk that the furnace flue action will be impaired, and a hazardous back-drafting condition may occur. The effect is greatest in tightly sealed houses where both a furnace and a fireplace are being operated at the same time - one may cause the other to back-draft, thereby drawing toxic combustion gases into the house air.

When a house is retrofitted, its thermal efficiency is increased, and the heating demands on the furnace are reduced. As a result, the furnace will operate less frequently. When a furnace is operating, its hot flue experiences a strong vertical

draft which draws air from the house and reduces the air pressure in the house. This reduced air pressure promotes air leakage into the house, through various parts of the building envelope. This inward flow of cold, dry air reduces the risk of moisture build-up and damage in the building envelope. Thus, in many older houses, the furnace plays a useful role in controlling moisture damage. If the furnace operates less frequently, the moisture-control effect is weakened and there will be an increased risk of moisture damage. It is essential to take this factor into account when considering furnace replacement options.

The range of furnace options has increased rapidly in the last few years. At the time of this project the first energy-efficient furnace designs had just become available on the market. These had thermal efficiencies typically in the range 75% to 85%, and were fitted with such features as automatic flue dampers, electronic ignition and two-speed fans. A new generation of furnace designs, with efficiencies around 90%, was just beginning to appear on the market in some areas. These units extracted practically all of the useful heat from the combustion gases. The exhaust gases were therefore relatively cool, and the units did not require a flue.

Furnace rooms are now becoming popular in energy-efficient houses. These are essentially airtight rooms built around the furnace and the DHW heater. Sometimes, the room may be insulated from the rest of the house. According to the gas codes, such rooms must be equipped with combustion and draft air ducts of prescribed size. The furnace, when operating in such a room, uses cold exterior air rather than warm house air. This increases the overall thermal efficiency of the house. At the same time, by isolating the furnace from the rest of the house, the flue no longer draws air through the house envelope. This has two consequences: first, it reduces infiltration heat loss and thereby improves the thermal efficiency of the house; secondly, because of the reduced infiltration of cold air, the risk of moisture damage in the house envelope is increased.

The same consequences exist wnenever a furnace is replaced by one which has less flue action. Examples of this are electrical furnaces, which have no flue, and high-efficiency gas furnaces, which have negligible flue action.

8.3 Factors affecting the choice

For reasons given earlier, it was anticipated that the sealing work on the house would fail to produce a high level of airtightness. Accordingly, the retrofitted house would have enough air infiltration to satisfy the needs of all the combustion appliances simultaneously: furnace, fireplace and domestic hot water heater. It was therefore decided that no special combustion air supply would be needed.

Conversely, a house with this reduced level of air infiltration will run the risk of moisture damage. This risk can be reduced by the flue action of the combustion appliances, therefore the flues should be allowed to exert their full effect on the house envelope. This eliminated three design options:

- Electrical furnaces
- High efficiency gas furnaces of the condensator type.
- A sealed furnace room around the furnace and DHW heater.

This left two options: a standard furnace unit with an efficiency of about 70% or a 'first generation' energy-efficient furnace with an efficiency of about 80%. Two factors favoured the use of a standard unit: first, there were concerns that the energy-efficient design might not display enough flue action because of the automatic flue damper (note that this damper does not close off the flue completely, since it is bypassed by the DHW flue connection, but some reduction in flue action was anticipated). Secondly, the energy-efficient furnace had

a much higher cost than the standard furnace (at that time) and could not be justified on the grounds of cost-effectiveness. Accordingly, it was decided to use a standard furnace unit as a replacement. This decision was reinforced by the availability of a high capacity standard unit (125,000 Btuh) at a reduced cost. It was felt that such a unit, with its high oversize factor, would consume slightly more energy but at the same time would give better protection against moisture damage.

A similar cost-effectiveness factor determined the choice of the replacement domestic hot water heater. New, energy-efficient DHW heaters were available at that time, but they cost about twice as much as a standard unit. It was therefore decided to use a standard unit.

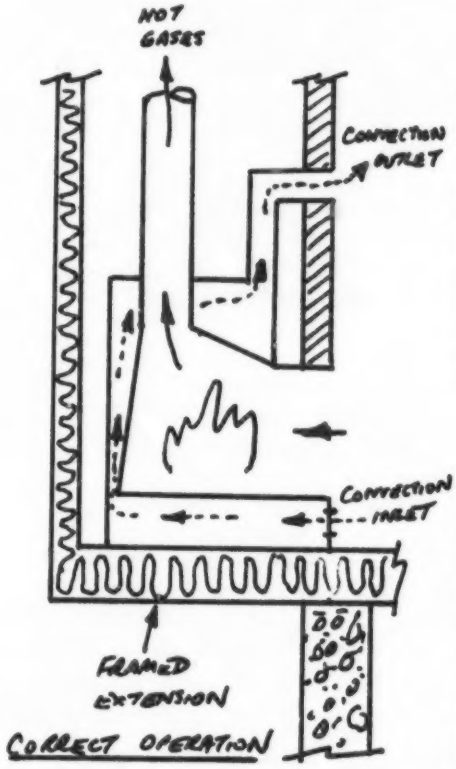
The existing air distribution duct system was considered to be poorly designed, giving poor heat distribution to some rooms because of the positions of the warm air registers and cold air returns. It was decided to conduct low-cost improvements on the ducting, to correct the main defects.

8.4 Details of the upgrading work

A new furnace unit and domestic hot water heater were installed. These were of standard design and performance. The furnace was fitted with a powered humidifier system, complete with humidistat control.

The ductwork was modified and balanced, to give a better distribution of warm air to the various parts of the house.

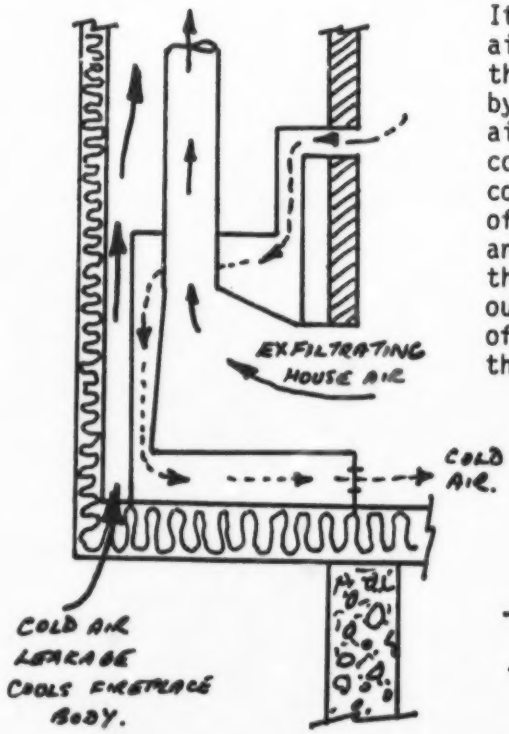
The existing main gas line was judged to be in poor condition and was replaced.



9.1 Assessment

The fireplace had been installed recently and was mounted inside a framed extension added to the north wall of the house. Few of the details of the installation were visible at the time of the preliminary inspection, but a strong draft of cold air was detected through the convection ports on the front of the unit. This was contrary to the way they should have behaved, and suggested that a more detailed inspection would be necessary.

A section of the framed extension was removed on the outside of the house to allow visual inspection of the back of the unit. This revealed the loss of vermiculite from the exterior walls, as mentioned earlier. The unit was found to be of good quality and was ULC approved. The insulation around the unit was fairly good, but not much attention had been paid to sealing of the ducts or sealing of the framed structure. Evidence of this was provided in the shape of a bees' nest under the fireplace, and inside the framed structure.



SUSPECTED OPERATION WITH NO FIRE.

It appeared that the leaky construction was allowing air to flow through the framed structure and around the metal body of the fireplace - probably induced by the flue, which was warmer than the surrounding air due to the house air flowing up it. This induced cold airflow, around the outside of the fireplace, cooled the metal shell and induced a reversed flow of convection air, which gave its heat to the shell and emerged from the lower ports as cold air. Thus, the fireplace was losing heat unnecessarily to the outside by two mechanisms: continuous exfiltration of air up the flue and continuous loss of heat through the metal body.

9.2 Details of upgrading work

The two main processes of heat loss were by air infiltration through the framed extension, and by exfiltration of house air up the chimney flue, which had a defective damper. The upgrading was therefore concentrated on remedying these two defects.

A good flue cap damper, tested and approved by the Alberta Research Council, was installed at the top of the chimney, and provided with a manual control at the fireplace.

Caulking was applied at all openings in the framed extension, particularly around the plywood base under the supporting joists.

When the retrofit work was in progress it was discovered that the electrical and plumbing systems contained a number of sub-standard features:

- The water system contained a mixture of iron and copper pipes, with corrosion at some joints.
- A drain system for the washing machine had been connected incorrectly into the main drainage system and was emitting sewer gases.
- The plumbing system in the upstairs bathroom showed signs of earlier trouble, and it was believed that the system might be leaking somewhere between the floor joists.
- The electrical system consisted of a mixture of installations of various ages. Some knob-and-tube wiring was visible in the attic, and was believed to extend downwards into some partition walls. Newer cable work had been improperly connected to old circuits with simple 'pig-tail' junctions.
- During the recent re-modelling, several electrical outlets had been installed in the floor rather than the wall, but the designs of these were not suitable for floor mounting.

Plumbing and electrical inspectors were called in to advise on the work required to bring each system up to an acceptable standard. Both inspectors called for an almost total replacement of the systems. In doing the required work, several problems were encountered. Floorboards had to be lifted to give access to the bathroom plumbing. This led to extra costs in fitting new floor covering in the bathroom. A complete overhaul of the electrical system was found to be impossible without doing a lot of damage to walls and floors. The electrical inspector allowed some concessions.

When an electrical system is being subjected to a major change, the electrical inspector usually takes this opportunity to have the system improved to prevailing standards. In this instance the service panel capacity was too small for current standards, and the existing service inlet was incorrectly located. The inspector therefore asked for a re-

location of the service inlet. A new service inlet was installed on the south-west corner of the house, closest to the utility distribution line serving the building. This meant that the service panel had to be re-located near this corner also, requiring a general re-routing of all the house circuits. These various changes added considerably to the cost of the upgrading work.

Two lessons can be drawn from these experiences:

- It is always advisable to have a thorough electrical and plumbing inspection at an early stage of a major retrofit project. This helps to define the problems and costs at the outset.

- Allowance should be made for the fact that the house may contain hidden defects which will become apparent only when the retrofit work is in progress. With proper electrical and plumbing inspections, the inspectors should be able to advise on the likelihood of hidden problems.

All damaged surfaces, resulting from retrofit work or relocation of electrical outlets, were repaired and finished.

One wall in the stairwell was in bad condition, with extensive cracks and bulges. Originally, it was proposed to fill the cracks and re-paint the wall. However, with the requirements for electrical circuit changes and duct modifications, it was decided to remove the existing plaster and install a new surface. This gave access to the wall cavity and simplified some of the utility work.

The existing basement stairwell was poorly finished and detracted from the demonstrational impact of the house. It was therefore decided to re-surface the stairwell, since this would be a well-used access to the proposed demonstrational displays in the basement.

For details of costs, projected energy savings and conclusions about this project, the reader is referred to the Overview Report, which is the first in this series of reports.

For further details of the work, the materials and the techniques, the reader is referred to the following Appendix, which consists of the detailed specifications as given in the contract documents.